# Gradient Analysis of Exotic Species in *Pinus radiata* Stands of Tenerife (Canary Islands)

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**Abstract:** Identifying the factors that influence the spread of exotic species is essential for evaluating the present and future extent of plant invasions and for the development of eradication programs. We randomly established a network of 250 plots on an exotic *Pinus radiata* D. Don plantation on Tenerife Island in order to determine if roads and urban centers are favouring the spread of exotic plant species into the forest. We identified four distinct vegetation groups in the *P. radiata* stands: advanced laurel forest (ALF), undeveloped laurel forest (ULF), ruderal (RU), and Canarian pine stand (CPS). The groups farthest from roads and urban nuclei (ALF and CPS) have the best conserved vegetation, characterizing by the main species of the potential vegetation of the area and almost no exotic and ruderal species. On the other hand, the groups nearest to human infrastructures (ULF and RU) are characterized by species from potential vegetation's substitution stages and a higher proportion of exotic and ruderal species. The results indicate distance to roads and urban areas are disturbance factors favouring the presence of exotic and ruderal species into the *P. radiata* plantation. We propose the eradication of some dangerous exotic species, monitoring of the study area in order to detect any intrusion of alien species in the best conserved areas and implementation of management activities to reduce the perturbation of the ULF and RU areas.

**Keywords:** Alien species, DCA, detrended correspondence analysis, distance to roads, distance to urban nuclei, TWINSPAN, two way indicator species analysis.

## INTRODUCTION

The invasibility of ecosystems can be described by a diverse number of factors like climate, geology, historic land use, landscape context, native plant richness, competition with natives, and natural or anthropogenic disturbances [1-5]. Two of the most important traits shaping the vulnerability of ecosystems to plant invasion are disturbances [3, 6], which create favourable conditions for alien plants establishment, and propagule pressure, which provides more opportunities for establishment, persistence, naturalization and invasion of exotic species [6, 7].

One of the main factors of disturbance of ecosystems around the world is road infrastructure [8, 9], which has proven to have important effects on the native vegetation of oceanic islands [10, 11]. Human corridors contribute to ecosystems invasion by 1) creating new favourable habitats for exotic species establishment [12, 13], 2) stressing or removing native species [12, 14], 3) facilitating the exotic species' movement by natural or human vectors [8, 10] and 4) providing an important source of exotic plant propagules [15]. In addition to roads, the distance to urban nuclei is an important factor influencing the richness of exotics in ecosystems [16, 17]. In these modified areas the successful invasions are frequent [18], and the horticulture activities that take place are an important pathway for the introduction of alien species [16, 19]. Due to this, urban nuclei contribute to the spread of exotic species into natural areas, acting as an important source of propagule pressure [20].

The Canary archipelago is situated amongst the most heavily roaded European territories [21]. Moreover, in the last four decades the population has doubled, leading to bigger and more urban nuclei [22]. Tenerife Island has a population density of 419 inhabitants per km$^2$, a value above the highest densities of other European Union communities [22]. The island has a total area of 5692 ha occupied for roads, which cover approximately 2.8% of the island's surface. This situation is of concern in the protected forest areas, where it has been proven that exotic species are expanding along roads [23-25], and that the urban nuclei are contributing to their expansion [23, 25].

Most of the actual forests of the Canary Islands are a result afforestation that took place mainly between 1930 and 1950 [26]. *Pinus canariensis* Chr. Sm. Ex DC. and to a lesser extent *Pinus radiata* D. Don (approximately 2200 ha in Tenerife Island) were the primary species on these plantations, and they were planted principally in areas with a potential vegetation of Canarian pine forests, but also in areas where laurel forests dominated [26, 27]. As a result, the forested areas of Tenerife Island today occupy a larger surface when compared to their historical distribution [27, 28]. Currently, the potential vegetation of these areas seems to be in a good regeneration state [29]. The increase of protected areas (approximately 48% of the Tenerife Island surface) as well as the socioeconomic changes of the last few decades (abandonment of traditional land use practices, increase of intensive cultivation and touristic development) also contributed to the recuperation of the forests by

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decreasing or eliminating forestry exploitation, agriculture and grazing activities. As a result of increasing protected areas and ceasing many historical land use activities, we believe road infrastructures and urban nuclei are the most prevalent ways for exotic species to invade the forest ecosystems of Tenerife Island [30].

The main objectives of this study are to determine to what degree the *P. radiata* plantations of Tenerife Island are being affected by exotic plant species and to find out if the presence of these species is related to the distance to paved roads and urban nuclei. Our main hypothesis is that the nearer the roads and urban nuclei are to the studied plots, the higher the number of exotic and ruderal species. Identifying the factors that influence the spread of exotic species is essential for evaluating the present and future extent of plant invasions and for the development of eradication programs [1, 31]. Consequently, determining the extent to which distance to roads and urban nuclei are leading to the invasion of Canary Island forested areas is fundamental in designing adequate restoration and management programs of these protected areas.

## MATERIAL AND METHODS

### Study Site

The study was carried out in the north-east slope of the Corona Forestal Natural Park and Reserva Especial de las Palomas on Tenerife Island (28°19′N, 16°34′W), Canary Islands, Spain. The park comprises 46336 ha, and is the biggest natural protected area and one of the most extensive forest bodies of the Canary Islands. Most of the forests of the park today are a result of reforestation conducted between 1930 and 1950. These plantations mainly consist of *P. canariensis* (25% of the park) and to a lesser degree *P. radiata* (approximately 2% of the park) [26, 27]. Our study area was planted with *P. radiata* between 1948 and 1952.

The vegetation of the area is comprised of laurel forest (between 600 and 900 m a.s.l.) dominated by *Laurus novo-canariensis*, *Erica scoparia*, *Erica arborea*, *Ilex canariensis*, *Persea indica*, *Prunus lusitanica*, *Myrica faya* and *Viburnum rigidum*, and Canarian pine forest (between 1000 and 2000 m a.s.l.) dominated by *P. canariensis*, and including different understory species like *Adenocarpus foliolosus, Bystropogon organifolium, Chamaecytisus proliferus, Erysimum bicolor* or *Lotus campylocladus*.

The annual precipitation of the park reaches 900 mm but that amount is doubled if fog drip is considered [32]. The average annual temperature is 15 °C. The altitudinal range of the plots is 350 m, implying differences in temperature not over 2 °C (as well for maximums and minimums), and differences in precipitation around 90 mm [33]. Soils at the study site have been classified as Entisols, suborder Orthents [34]. Nomenclature and status of species follow Acebes *et al.* [35].

### Vegetation Sampling

We randomly established 250 quadrat plots of 10 × 10 m in size in the *P. radiata* stands. We recorded all the species present in each plot and estimated their percent cover using a 10 point scale (1: traces, 2: <1% of cover in the plot, 3: 1-2%, 4: 2-5%, 5: 5-10%, 6: 10-25%, 7: 25-50%, 8: 50-75%, 9: >75%, 10: 100%).

We recorded environmental characteristics of the plots, specifically altitude, slope, percentage of bare soil and litter (using same 10 point scale used for species cover), and canopy cover (using a convex spherical densiometer) [36]. We used the software ArcGIS version 9.1 (ESRI) to determine the distance from each plot to the nearest roads and urban nuclei. Sampling was conducted between October 1999 and March 2000.

### Statistical Methods

We used the TWINSPAN method (Two Way Indicator Species Analysis; [37, 38]) to get a classification of ours samples based on their species composition. This divisive and hierarchical technique [37] constructs groups in which constituent species can be considered good indicators of ecological conditions [39]. TWINSPAN uses the quantitative information of the cover for the classification. We highlighted the differences in the same species covering 1% of the plot or 50% of the plot creating "TWINSPAN pseudospecies" [37]. We used four categories for the species in relation to their cover at the plot: category 1 means that the species is between 0 and 1 cover classes; category 2 is more than cover class 1 and less than class 2; category 3 more than class 2 and less than 4; and category 4 means more than 4 cover class. In our case, we lessened differences at low cover percentages to increase the calculated dissimilarities. Classes 2 and 3 were given twice the weight of class 1, while class 4 was three times the weight of class 1 and twice that of classes 2 and 3.

We used the indirect gradient analysis technique of DCA (Detrended Correspondence Analysis; [40]) to examine how species composition changed through space and whether different classes found with the TWINSPAN method could be extrapolated from the analyses. Analysis was based on the species cover classes and was implemented with the software CANOCO [41].

We used the non parametric Kruskal-Wallis test to look for differences in the distance to roads, distance to urban nuclei and richness values between the vegetation groups defined by the TWINSPAN analysis. We used non parametric tests because the lack of normality and homocedasticity of the data. Normality of the data was tested with the Shapiro-Wilk test, and homoscedasticity of the data was tested with a multiple $F$ test, using a p-value $< 0.05$ in both cases. Basic statistical methods followed Zar [42] and were applied with the SPSS statistical package [43].

## RESULTS

We found seven exotic species (not including *Pinus radiata*) and a total of eighty species in the studied plantations. The alien plant species found were: *Ageratina adenophora, Eucaliptus globulus, Linum bienne, Lotus angustissimus, Oxalis pes-caprae, Rumex acetocella* and *Stellaria media.* All the species belong to different families, and with the exception of *E. globulus*, all of them are herbaceous species.

TWINSPAN analysis based on species cover classes showed four groups. Based on the species present in the understory of the *P. radiata* stands in each group, we identified them as: advanced laurel forest (ALF), undeveloped laurel forest (ULF), ruderal (RU), and Canarian pine stand (CPS). The ALF group is dominated by species like *Laurus novo-canariensis*, *Ilex canariensis* and *Viburnum rigidum*, typical from the laurel forest potential vegetation. In the ULF group, the laurel forest species are also present, but in this case there is an important presence of ruderal species like *Brachypodium sylvaticum*, *Galium scabrum* and *Vicia lutea*. The presence of a high number of ruderal species (*Sonchus oleraceus, Trifolium arvense, Tuberaria guttata, Anagallis arvensis*, *Stachys arvensis, etc*) stands out in the RU group. Finally, the species composition of the CPS group is more characteristic of Canarian pine forests, and *P. canariensis* shares the canopy cover with *P. radiata*.

The DCA biplot for the site and species scores (for axes I and II) is shown in Fig. (**1**). In this graph different symbols have been assigned to the plots of the groups defined by TWINSPAN analysis. In the first axis we can observe a gradient from species characteristic of the laurel forest (*Prunus lusitanica, Picconia excelsa, Ilex perado* or

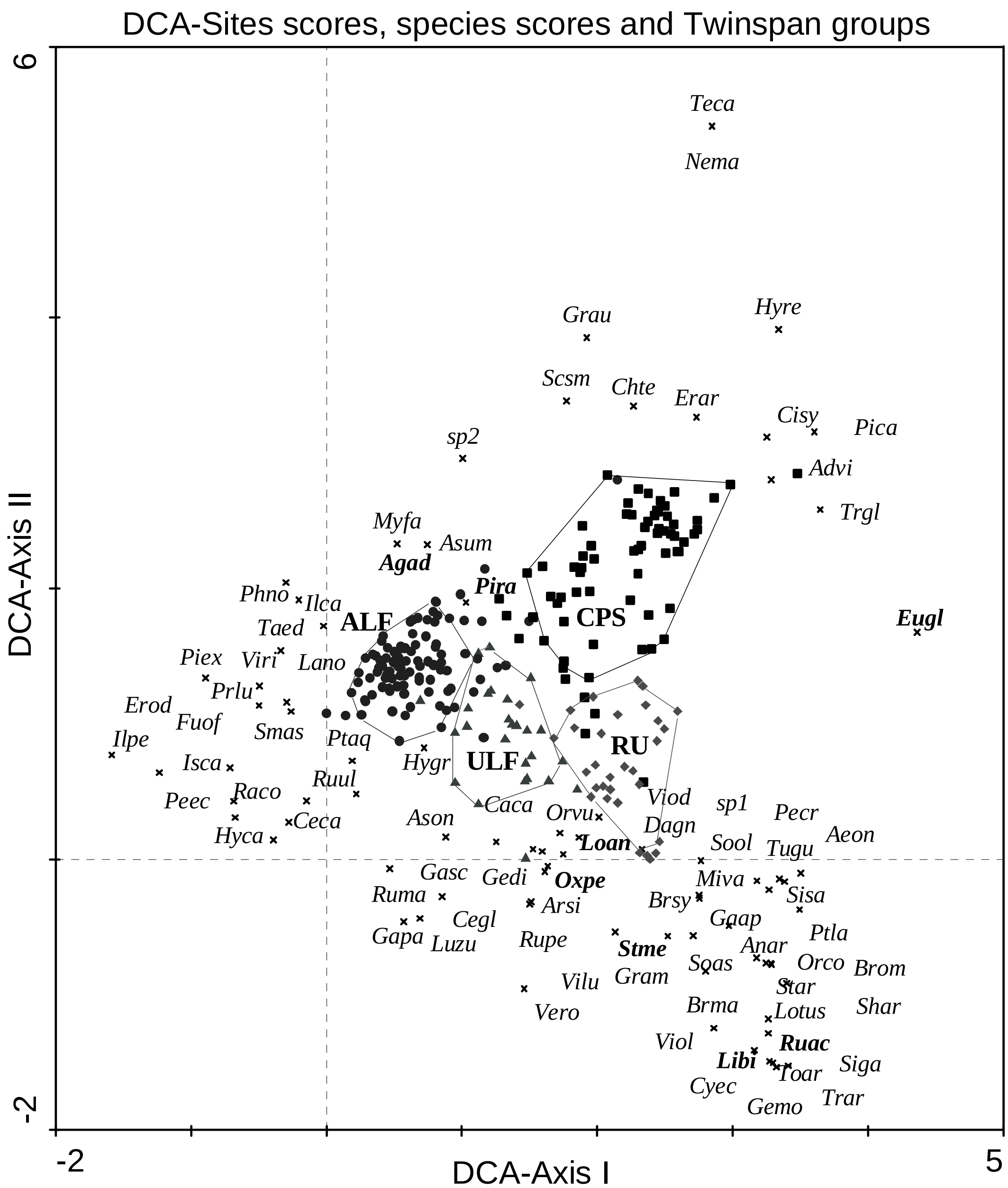


**Fig. (1).** Species and site scores for the first and second axis of the DCA based on cover of the species (eigenvalues were 0.463 and 0.348, respectively, and the cumulative percentage variance of species data of both axes was 14.4). The plots belonging to the different TWINSPAN groups are represented with the following symbols: ● ALF, ▲ ULF, ♦ RU, ■ CPS and are enclosed by polygons, which include 95% of the plots of each group. Species are labelled with the first two letters of the genus followed by the first two letters of the specific epithet (As they appear in Appendix A). The exotic species are in bold.

*Isoplexis canariensis*) on the left to ruderal species (*Sherardia arvensis, Trifolium arevense, Silene galica* or *Galium parisiense*) on the right. This indicates an ALF-ULF-RU gradient. The second axis shows a gradient from the species typical of the Canarian pine forest (*Teline canariensis, Neotinea maculata, Hypericum reflexum* or *Cistus sympithifolius*) to the ruderal species. Although this second gradient separates the CPS from the RU group, the species composition of the RU group is more related to the pine forest than to the laurel forest, but the dominance of the ruderal and exotic species in this group displays this gradient.

The exotic species are principally common in the RU group, although they also appear in the ULF group. There are only two exotic species that do not appear in any of these groups: *Ageratina adenophona* which appears mainly in the ALF group and *Eucaliptus globulus* which is present only in the CPS group.

The Kruskal-Wallis test showed that the vegetation groups discriminated by the TWINSPAN differ in their distance to the nearest paved roads ($X^2_{3,245}$=31.181, $p < 0.01$; Fig. **2a**) and in their distance to the nearest urban nuclei ($X^2_{3,245}$=51.088, $p < 0.01$ Fig. **2b**). The groups containing most of the ruderal and exotic species (RU and ULF) are closer to these elements. The RU group is the nearest to both disturbance factors, while the ULF group is also close to paved roads. These two groups have the highest richness values ($X^2_{3,245}$=152.659, $p < 0.01$; Fig. **2c**). On the other hand, ALF and CPS, the groups that have less ruderal and exotic species, are a greater distance from these disturbance factors and also have lower species number. A description of the abiotic characteristics of the groups can be found in Table **1**.

## DISCUSSION

We found 8.75% of species in the *P. radiata* stands were exotic. We did not include *P. radiata* in this percentage because it is a shade intolerant species that does not show regeneration in the study area [29]. The vegetation of the *P. radiata* stands could be classified in four groups. Two of them, the advanced laurel forest group (ALF) and the Canarian pine stands group (CPS), have the best conserved vegetation, characterizing by the main species of the potential vegetation of the area and almost no exotic and ruderal species. These groups are the farthest from paved roads and urban nuclei and have smaller richness values. On the other hand, the undeveloped laurel forest group (ULF), which is nearer to roads than the ALF and CPS groups, has the characteristic species of the laurel forest but they are accompanied by a remarkable number of ruderal species and some exotic species in the understory. This group also has high richness values, which can be a feature of disturbed ecosystems [44, 45]. Finally, the ruderal group (RU), which is more related to Canarian pine forests than to laurel forests, has the highest proportion of exotic and ruderal species as well as the highest species richness, typical traits of plots close to trails or those affected by other disturbances [26]. These results support our hypothesis that roads and urban nuclei are affecting the species composition of the nearest ecosystems, favoring the invasion by ruderal and exotic species [23-25]. Our results suggest that when both factors are present, as in the case of the RU group, the effects on the vegetal communities are more evident than if only one is present, as in the case of the ULF group.

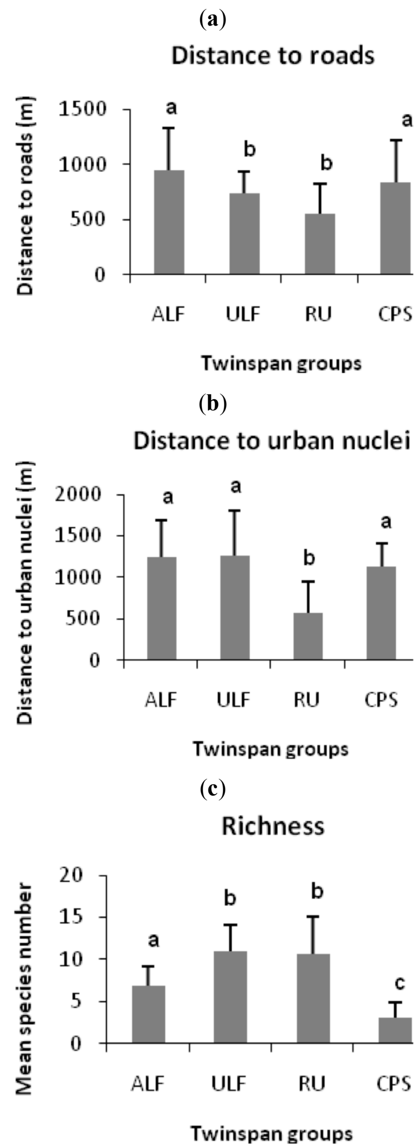


**Fig. (2).** Mean values and standard deviations for (**a**) distance to roads (meters); (**b**) distance to urban nuclei (meters); (**c**) richness (species number). Identical letters above the bars indicate non-significant differences.

Road infrastructure is one of the main ways exotic plant species invade natural areas, especially for generalist annual species [10, 46, 47]. The edges of these corridors provide adequate habitats for the exotic species' establishment, facilitating their dispersion [48]. Several studies show that a considerable number of ruderal and exotic species are spreading along road edges in the Canary Islands [23-25] even finding nearly three times as many species (including native and non-native species) on the road edge than 90 m inside of the laurel and pine forests [49]. Although in these studies the alien species' presence was limited to a few meters inside of the forests we found a significant number of alien species inside of the *P. radiata* stands. This divergence might be a result of the differences in the forested areas. In our study, the sites are not natural laurel and Canarian pine forests but an exotic pine plantations. In *P. radiata* stands, forest uses have been carried out to decrease the populations of this pine species, and the disturbances generated by these activities might be allowing alien and ruderal species to invade the interior of the forests [50].

**Table 1. Mean Values for Altitude (Meters); Slope (Sexagesimal Degrees); Canopy Cover (Mean of the Percentages); and Litter, Rock and Soil Cover (Mean of Cover Classes for the Plots) of the Different Groups Discriminated by TWINSPAN Analysis**

| | ALF | ULF | RU | CPS |
|---|---|---|---|---|
| **Altitude** | 974.75 | 1029.31 | 1122.97 | 1222.03 |
| **Slope** | 16.99 | 8.58 | 8.56 | 11.73 |
| **Canopy cover** | 87.52 | 75.72 | 82.36 | 81.88 |
| **Litter** | 8.96 | 8.42 | 8.22 | 8.51 |
| **Rock** | 1.92 | 2.23 | 3.81 | 3.99 |
| **Soil** | 1.21 | 1.81 | 2.13 | 1.82 |

When close proximity to roads is combined with a short distance to urban nuclei, the presence of alien species in the *P. radiata* stands is even greater. Distance to population nuclei has proven to be an important factor determining the richness of ruderal and exotic species in forests [16, 17]. In the Canary Islands the number of ruderal and exotic species presents in roads decreases as the distance to the urban nuclei increases [23, 25]. These results support the hypothesis that the combination of both factors could make the invasion process stronger.

Three of the exotic species found in this study are considered highly invasive in the Canary Islands: *Ageratina adenopora* [51], *Oxalis pes-caprae* [52] and *Eucalyptus globulus* [28]. The first of these has been frequently found on the road edges of the Canarian ecosystems [23, 25, 49], but it also appears in natural ecosystems [53] in competition with the native and endemic flora. We found this species mainly in the laurel forest, which is considered the most representative Canarian ecosystem [54]. Avoiding the expansion of this species into the laurel forests must be of primary importance for the management of this protected area. We suggest that eradication plans should be implemented for this species as soon as possible. *O. pes-caprae* mainly invades ruderal, agricultural, grasslands and old-field habitats [55]. In the Canary Islands this species has been found mainly on road edges [23-25] and in pasture communities [56]. It was not frequently found in the *P. radiata* stands, and it appeared mainly in the disturbed plots, so in this case eradication measurements are not necessary, although a monitoring of the species must be carried out. Finally, *E. globulus* is an exotic species that was introduced to the Canary Island for forest purposes. The presence of this species in the CPS group plots is restricted to areas where it was originally planted. This species does not show regeneration but produces changes in the chemical properties and nutrient impoverishment of the soils [57]. Because of this and because its forest use is not current, we suggest the elimination of this tree species of the studied areas.

The rest of the exotic species found in this study are not highly invasive and appear mainly in more disturbed areas. Therefore we recommend continued monitoring of the study site in order to detect any intrusion of the alien species in the best conserved places. Moreover in the RU and ULF group areas, management activities should be implemented to reduce the perturbation of the ecosystem and to promote successful regeneration of the potential vegetation [29].

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## APPENDIX A

Species found in this study and labels given to them in the DCA analysis. Exotic species are given in bold.

| Species | Labels | Species | Labels |
|---|---|---|---|
| Adenocarpus viscosus | Advi | Myrica faya | Myfa |
| Aeonium sp. | Aeon | Neotinea maculata | Nema |
| **Ageratina adenophora** | **Agad** | Origanum vulgare | Orvu |
| Anagallis arvensis | Anar | Ornithopus compressus | Orco |
| Arisarum simorrhinum | Arsi | **Oxalis pes-caprae** | **Oxpe** |
| Asparragus umbellatus | Asum | Pericallis cruenta | Pecr |
| Asplenium onopteris | Ason | Pericallis echinata | Peec |
| Brachypodium sylvaticum | Brsy | Phyllis nobla | Phno |
| Briza maxima | Brma | Picconia excelsa | Piex |
| Bromus sp. | Brom | Pinus canariensis | Pica |
| Carex canariensis | Caca | **Pinus radiata** | **Pira** |
| Cedronella canariensis | Ceca | Prunus lusitanica | Prlu |
| Cerastium glomeratum | Cegl | Pteridium aquilinum | Ptaq |
| Cheirolophus teydis | Chte | Pterocephalus lasiospermus | Ptla |
| Cistus symphytifolius | Cisy | Ranunculus cortusifolius | Raco |
| Cynosorus echinatus | Cyec | Rubia peregrina | Rupe |
| Daphne gnidium | Dagn | Rubus ulmifolius | Ruul |
| Erica arborea | Erar | **Rumex acetocella** | **Ruac** |
| Erodium sp. | Erod | Rumex maderensis | Ruma |
| **Eucaliptus globulus** | Eugl | Scrophularia smitti | Scsm |
| Fumaria officinalis | Fuof | Sherardia arvensis | Shar |
| Galium aparine | Gaap | Silene gallica | Siga |
| Galium parisiense | Gapa | Smilax aspera | Smas |
| Galium scabrum | Gasc | Sonchus asper | Soas |
| Geranium dissectum | Gedi | Sonchus oleraceus | Sool |
| Geranium molle | Gemo | Unknown sp. (1) | sp1 |
| Gramineae | Gram | Unknown sp. (2) | sp2 |
| Greenovia aurea | Grau | Stachis arvensis | Star |
| Hypericum canariense | Hyca | **Stellaria media** | **Stme** |
| Hypericum grandifolium | Hygr | Tamus edulis | Taed |
| Hypericum reflexum | Hyre | Teline canariensis | Teca |
| Ilex canariensis | Ilca | Torilis arvensis | Toar |
| Ilex perado | Ilpe | Trifolium arvense | Trar |
| Isoplexis canariensis | Isca | Trifolium glomeratum | Trgl |
| Laurus novo-canariensis | Lano | Tuberaria guttata | Tugu |
| **Linum bienne** | **Libi** | Veronica sp. | Vero |
| Lotus | Lotus | Viburnum rigidus | Viri |
| **Lotus angustissimus** | **Loan** | Vicia lutea | Vilu |
| Luzula sp. | Luzu | Viola odorata | Viod |
| Micromeria varia | Miva | Viola sp. | Viol |

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